BSR 4175

Laser Geodynamic Satellite Thermal/Optical/Vibrational Analyses and Testing

Final Report Addendum

Volume I

Executive Summary

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Contract NAS 8-30658

January 1975

Prepared for:

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812

Bendix Aerospace Systems Division

Ann Arbor, Michigan

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FOREWORD

This technical report presents the results of a retroreflector performance improvement program, conducted as part of the LAGEOS Phase B Thermal/Optical/Vibration Analyses and Test Program. The study was conducted by The Bendix Corporation, Aerospace Systems Division, for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, under Contract NAS 8-30658.

The results of this study, which are prepared and submitted in accordance with the data requirements of Contract NAS 8-30658, are contained in two volumes:

Volume I	Executive Summary
Volume II	Technical Report

The study effort was initiated in September 1974, and the technical effort was completed in December 1974. The study was conducted under the direction of Mr. C. W. Johnson, LAGEOS Program Manager at NASA/MSFC and Mr. J. M. Brueger, LAGEOS Program Manager at Bendix Aerospace Systems Division.

As in the initial study phase, the successful completion of this study effort was the result of the close cooperation and conscientious support of the various individual government and contractor representatives involved. In particular, the efforts of the following is acknowledged: J. Zurasky and J. Randall of NASA/MSFC; D. Arnold of SAO; E. Granholm, J. Monroe, and C. Sheppy of Bendix; C. Zanoni and S. Laufer of Zygo; M. Rimmer and R. Byrd of Itek; and W. Augustyn of Perkin-Elmer. In addition to his support in the overall study, Mr. Zurasky was responsible for the MSFC study of the effect of laser wavelength on dihedral angle selection, the results of which are included in this report.

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1.0 INTRODUCTION

This report, which is an addendum to the basic LAGEOS Phase B Final Report (Ref. A)*, describes the results of a 4-month add-on study effort that was conducted for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, from September 1974 through January 1975. The add-on study effort, which evolved from the results of the basic study analyses and testing efforts, sought to resolve a theoretical/test data paradox whose solution was also expected to identify a LAGEOS retroreflector design change for optical performance improvement.

The basic study analyses and test results, as presented in the LAGEOS PDR in September 1974 and described in the LAGEOS Phase B Final Report (Ref. A), indicated a paradox between the theoretical optical performance, as initially expected from geometric predictions for the nominal retroreflector dihedral angle, and the empirical optical performance, based on photometric measurements made directly in the return beam far-field diffraction pattern of the LAGEOS test retroreflectors. Predicted optical performance, as obtained from an ITEK retroreflector math-model and ray-trace analysis, indicated intensity levels falling between the geometric predictions and the far-field diffraction pattern test measurements. The direct impact of this paradox on LAGEOS was the expectation that retroreflector optical performance could be improved by the specification of the optimum dihedral angle, as determined and verified by additional analysis and test.

This volume provides an executive summary of the additional study program effort as defined by the contract documentation requirements (DR No. MA-04, DPD No. 296). Summarized herein are the study objectives, the study approach, the principal assumptions, the type of basic data generated, and the significant results. Other NASA and NASA-funded related efforts are identified. Reference is made throughout to appropriate sections of Volume II of this report which provide more detailed descriptions of analysis and test methods, generated data, and results. The study limitations, implications for research, and suggested additional efforts are also summarized.

2.0 STUDY OBJECTIVES

The overall purpose of this study effort was achieved through the accomplishment of the following study objectives:

- Determine the basis of the already demonstrated retroreflector optical performance evaluating measurement, analysis, and test data for the existing LAGEOS retroreflectors.

*References are listed in Section 9.0

- Identify the dihedral angle specification changes for retroreflector performance improvement on the basis of predicted optical performance.

- Verify the retroreflector optical performance improvement by analysis and test.

These objectives were met through the performance of a series of interrelated tasks and sub-tasks, as described in Section 4.

3.0 RELATIONSHIP TO OTHER NASA EFFORTS

This study, through the accomplishment of its objectives, is intended to support the overall NASA/MSFC LAGEOS Program. The other related NASA efforts are the LAGEOS design/fabrication effort at MSFC, the system evaluation effort at Smithsonian Astrophysical Observatory (SAO), the ground station effort at Goddard Space Flight Center (GSFC), the launch vehicle integration effort at GSFC/McDonnell Douglas Astronautics Company (West), and the LAGEOS flight retroreflector fabrication/test effort at the Electro-Optical Division of the Perkin-Elmer Corporation.

The analytical and test data generated in this study effort, and the results of the basic study effort previously reported in the earlier Final Report (Ref. A), have contributed to the support of these other NASA LAGEOS-related efforts. In particular, the results of this latest additional study effort, including the identification of the optimum dihedral angle for LAGEOS, contributed directly to the determination of the design and acceptance test requirements for the LAGEOS flight retroreflectors.

4.0 METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

4.1 Method of Approach

The approach used to achieve the study objectives is illustrated in the series of interrelated tasks shown in the logic network of Figure 4-1.

These tasks, described in greater detail in Volume II and in the Program Study Plan (Ref. B), are as follows:

- Task 1 - Retroreflector Dimensional Verification

Dihedral angles were determined for the existing LAGEOS test retroreflectors by analyzing Twyman-Green interferograms generated from these retroreflectors and by direct mechanical measurements. Independent mechanical measurements were made by three contractors.

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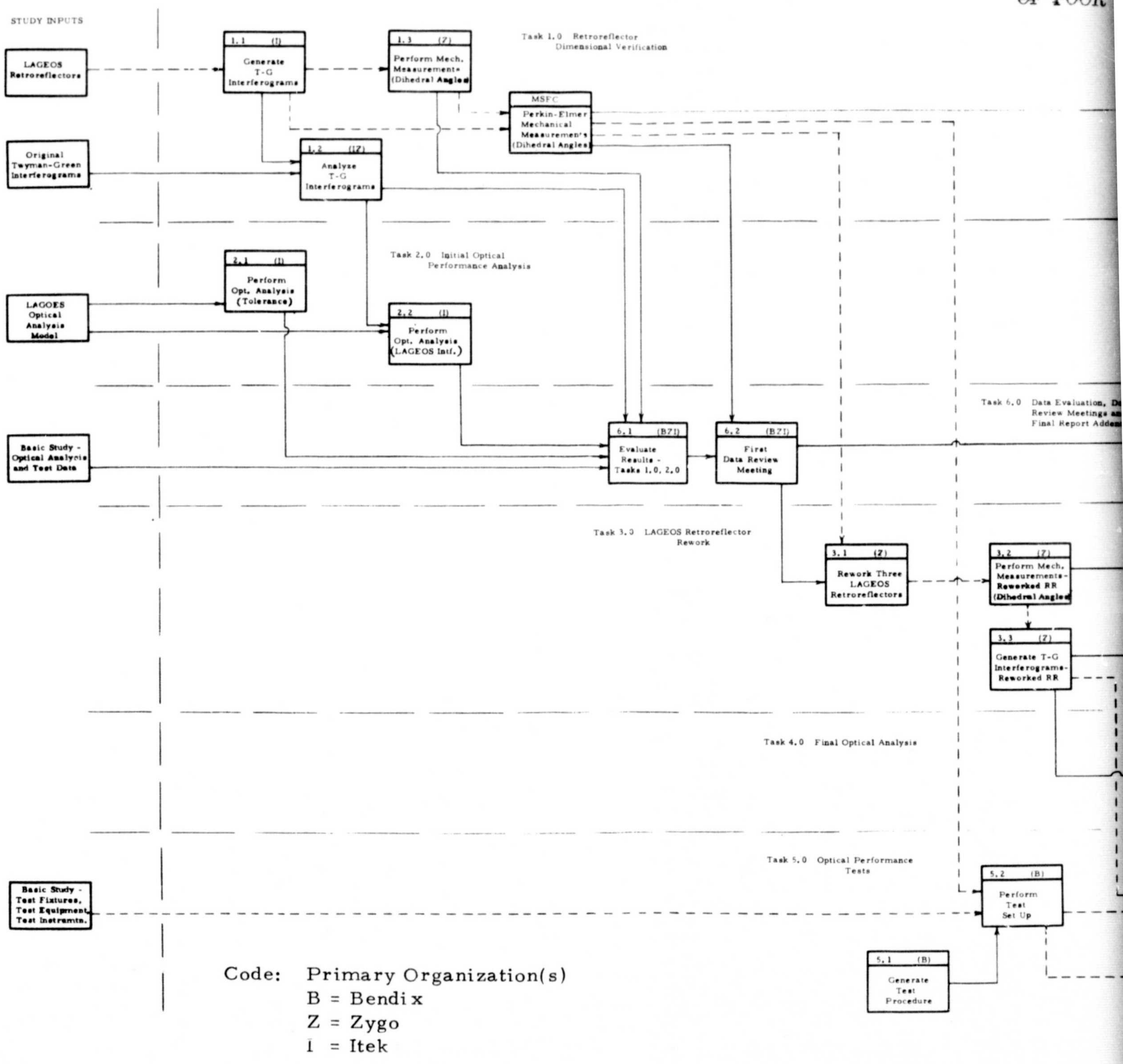

Code: Primary Organization(s)
B = Bendix
Z = Zygo
I = Itek

——————— Data Flow

- - - - - - - - - Hardware Flow

Figure 4-1 LAGEOS Retroreflector I

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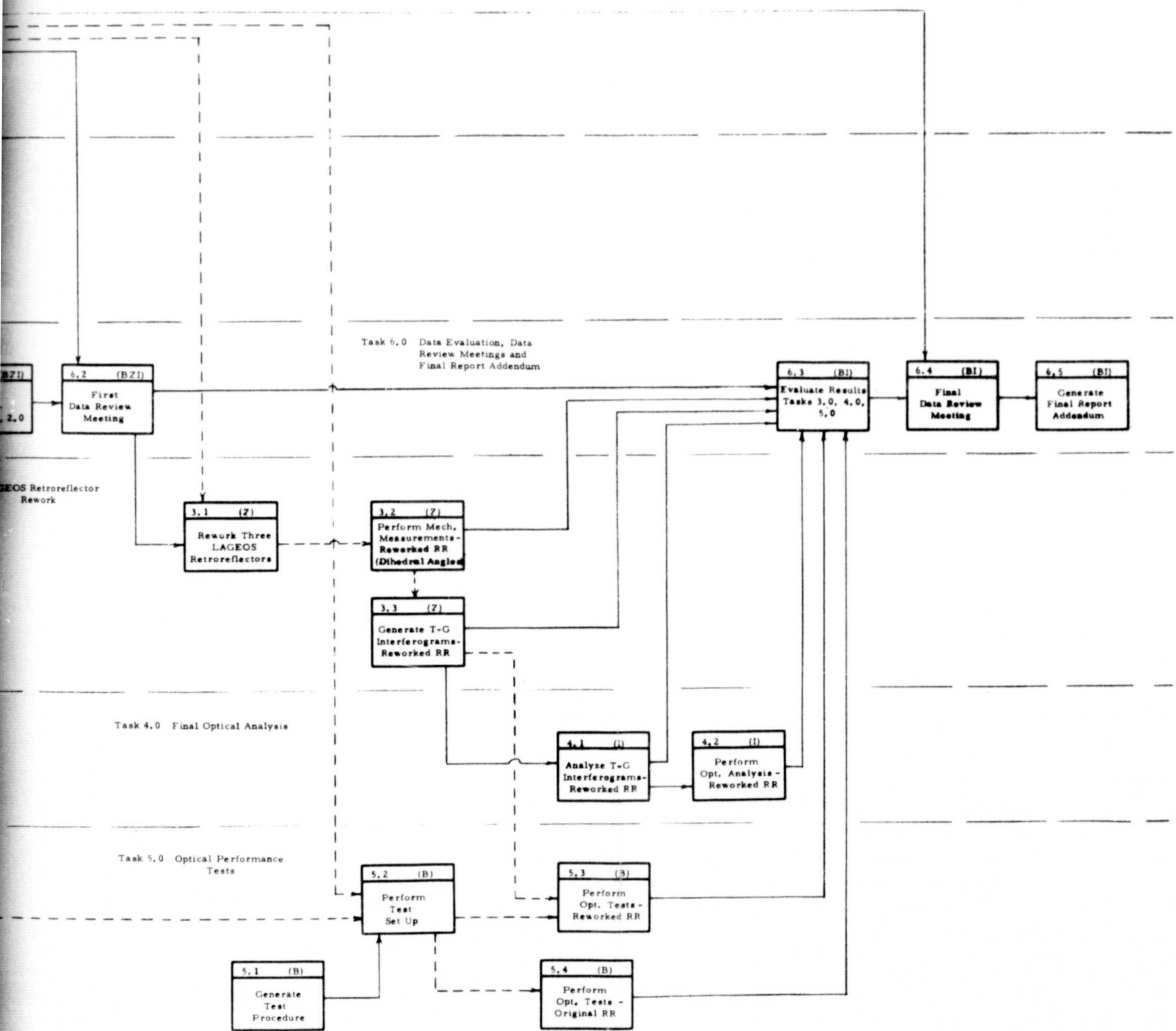

Figure 4-1 LAGEOS Retroreflector Improvement Study Logic Network

. Task 2 - Initial Optical Performance Analysis

Predicted relative intensity, within the LAGEOS annulus of the far-field diffraction pattern, as a function of dihedral angle was determined for ideal retroreflectors. Data was obtained for both nominal (equal) and off-nominal (unequal) dihedral angles. Predictions were also generated for the LAGEOS test retroreflectors by using the measured interferometric data to define the actual retroreflector characteristics.

. Task 3 - LAGEOS Retroreflector Rework

Three LAGEOS test retroreflectors were reworked to obtain a new set of dihedral angles on each retroreflector. The average values, which were intended to cover a range of lower dihedral angles, were defined from the results of Tasks 1 and 2 to permit the verification of the predicted performance improvement at the optimum dihedral angle. The resulting dihedral angles were then determined by mechanical measurements, and interferograms were generated for each reworked retroreflector.

. Task 4 - Final Optical Performance Analysis

Dihedral angles of the reworked retroreflectors were determined by analyzing the resulting interferograms. Far-field diffraction pattern optical performance was determined analytically for the reworked retroreflectors. The input characteristics used for the analysis were those defined from the interferograms for the reworked retroreflectors.

. Task 5 - Optical Performance Tests

Optical tests were performed to measure the relative intensity, in the LAGEOS annulus of the far-field pattern, of the reworked retroreflectors. Tests were also run on three original LAGEOS test retroreflectors to verify the test setup and instrumentation.

. Task 6 - Data Evaluation, Review Meetings, and Final Report

The data resulting from Tasks 1 and 2 were evaluated and then reviewed in a meeting at NASA/MSFC. This meeting, which included participation by NASA and all organizations involved in LAGEOS retroreflector performance, resulted in the selection of the dihedral angles to be incorporated in three LAGEOS test retroreflectors. It was concluded that test and analytical data from these reworked retroreflectors were

required to confirm the optimum dihedral angle predicted from ideal retroreflector analytical results.

In a final data review meeting, the results of Tasks 3, 4, and 5 were presented to representatives of NASA and other organizations involved in the LAGEOS retroreflector performance. The data evaluation resulted in the final recommendation for the LAGEOS dihedral angle. Subsequent to the review meeting, the recommended dihedral angle was confirmed in a NASA/MSFC evaluation of the effect of laser wavelength on the optimum dihedral angle.

4.2 Principal Assumptions

The principal assumptions that formed the basis for this study were:

- The retroreflector configuration is the 1.5-inch-diameter, circular-faced design with three integral mounting tabs as defined in MSFC Drawing 50M24461 (Revision J). The dihedral angles were varied in the study to determine the effects on performance.

- LAGEOS mission orbital parameters dictate a velocity aberration angle at the ground station of from 13.2 to 16.9 arc-seconds. Analyses and tests in this study were based on determining the integrated energy in the far-field diffraction pattern annulus from 13.2 to 16.9 arc-sec diameter.

- The laser wavelength for the analysis and tests in this study is 6,328 Å. Results of a NASA/MSFC evaluation of performance at other wavelengths are also presented in this report to provide the complete basis for selection of the LAGEOS dihedral angle.

5.0 BASIC DATA GENERATED AND SIGNIFICANT RESULTS

5.1 Basic Data Generated

The basic data generated in this study effort are provided, in detail, in Volume II and its appendices. A brief summary of only the most significant data is provided in this section.

The results of the mechanical measurements of the dihedral angles on three of the original LAGEOS test retroreflectors are shown in Table 5-1. Independent measurements were made by three organizations, as noted. Additional data are provided in Section 3 of Volume II.

TABLE 5-1

DIHEDRAL ANGLE MEASUREMENTS

Retroreflector S/N	Moore** (Arc Sec)*	Zygo Corp. (Arc Sec)* Operator #1	Zygo Corp. (Arc Sec)* Operator #2	Perkin-Elmer*** (Arc Sec)	Original Zygo **** (Arc Sec)
1	2.14 ± 0.02	2.10 ± 0.02	2.05 ± 0.03	1.7	2.00
	2.00 ± 0.07	1.67 ± 0.06	1.89 ± 0.07	1.7	1.24
	1.72 ± 0.09	1.55 ± 0.05	1.75 ± 0.03	1.7	0.92
2	1.68 ± 0.04	1.33 ± 0.02	1.63 ± 0.05	1.35	1.54
	1.84 ± 0.02	1.38 ± 0.06	1.81 ± 0.05	1.55	2.05
	1.76 ± 0.05	1.38 ± 0.03	1.76 ± 0.04	1.4	1.83
4	1.82 ± 0.02	1.68 ± 0.05	1.46 ± 0.03	1.65	2.00
	1.80 ± 0.03	1.24 ± 0.02	1.30 ± 0.05	1.5	1.57
	1.80 ± 0.06	1.23 ± 0.02	1.41 ± 0.02	1.5	1.60

* The average angles and standard deviations are based on five measurements of each retroreflector.

** Moore Special Tool Co., Inc.

*** Perkin-Elmer Corp., Electro-Optical Division

**** As performed on the basic study program.

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Interferometric measurements of these same dihedral angles, on all of the original LAGEOS test retroreflectors, were made in this study by Itek and are shown in Table 5-2. Detailed descriptions of the analytical method and the results are given in Volume II, Section 3.

Initial optical analysis results, as generated by Itek for the original six LAGEOS test retroreflectors, are shown in Figures 5-1 and 5-2. The results are based on the use of actual retroreflector characteristics, in terms of interferometric data for each LAGEOS test retroreflector. The results of Bendix optical tests, made in the basic study and reported in Ref. A, are also shown in the figures. The analytic method and detailed results are described in Volume II, Section 4.

The relative energy in the LAGEOS far-field diffraction pattern annulus as a function of dihedral angle is shown in Figure 5-1. In both Figures 5-1 and 5-2, dihedral angles are based on the Itek interferometric measurements. The analytical results for ideal nominal retroreflectors (i.e., having equal dihedral angles) are also shown and are identified as "tolerance study nominal cube".

The centroid of the energy distribution in the far-field diffraction pattern as a function of dihedral angle is shown in Figure 5-2. The data shown are from both analytical predictions and test results for the original LAGEOS test retroreflectors. Analytical predictions are also shown for ideal nominal and off-nominal retroreflectors (i.e., having positive tolerance, nominal, and negative tolerance dihedral angles) with and without polarization effects. Analytical predictions based on simple geometric considerations are also shown.

The mechanical measurements and interferometric measurements of the dihedral angles for the LAGEOS retroreflectors, reworked to smaller values of dihedral angle, resulted in the data shown in Tables 5-3 and 5-4, respectively. Additional data are given in Section 5 of Volume II. The interferometric data were also used to generate analytical predictions of the optical performance for these reworked retroreflectors. Detailed results are described in Section 6 of Volume II. The resulting predictions of the energy in the LAGEOS annulus are shown in Figure 5-3 along with the data previously generated for ideal retroreflectors and for the original LAGEOS test retroreflectors. The data are plotted at the interferometrically determined dihedral angles and at the mechanically determined dihedral angles. The centroid of the predicted energy distribution is plotted in Figure 5-4 for the reworked retroreflectors; also plotted are the data previously generated for ideal retroreflectors and for the original LAGEOS test retroreflectors. The reworked retroreflector data were plotted at both the interferometrically

TABLE 5-2

INTERFEROMETRIC MEASUREMENT OF DIHEDRAL ANGLES (ARC-SEC)*

Retroferflector S/N	INTERFEROGRAM 1			2			3			Average			Avg.
1	1.38	1.71	1.87	1.53	1.68	2.01	1.63	1.90	1.98	1.51	1.76	1.95	1.74
2	1.62	2.19	2.03	1.64	1.91	1.82	1.77	2.00	2.08	1.68	2.03	1.98	1.90
3	1.32	1.30	1.61	1.30	1.38	1.59	1.38	1.53	1.53	1.33	1.40	1.58	1.44
4	1.83	1.67	1.87	1.86	1.87	1.76	1.86	1.72	1.92	1.85	1.75	1.85	1.82
5	2.24	2.38	2.01	2.23	2.28	1.94	2.19	2.10	1.88	2.22	2.25	1.94	2.14
6	1.76	1.64	1.51	1.50	1.68	1.59	1.56	1.44	1.65	1.61	1.59	1.58	1.59
										Average			1.77

(1 σ = 0.07 Arc-Sec)

*Performed by the Itek Corporation, Optical Systems Division.

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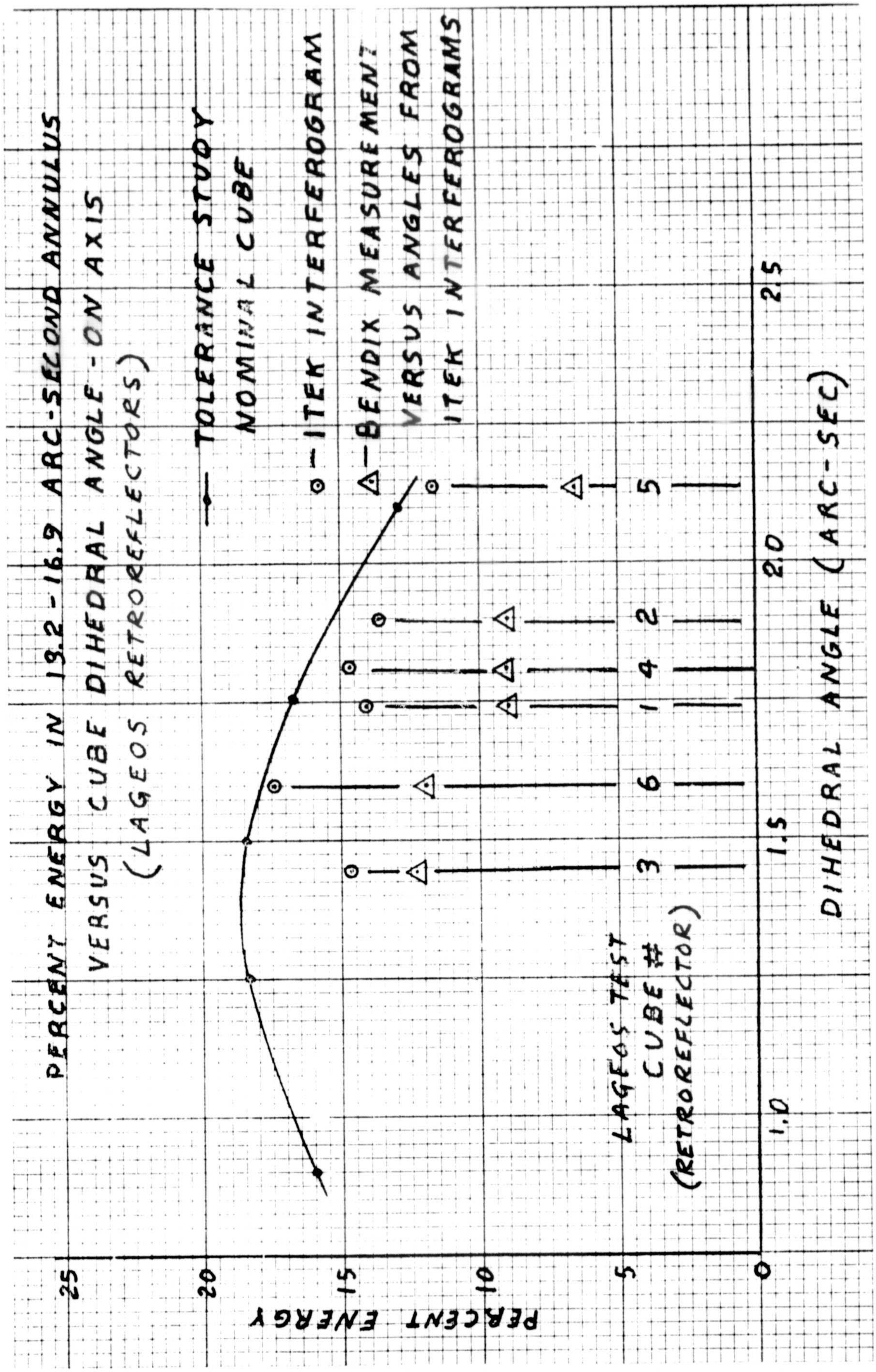
PERCENT ENERGY IN 19.2-16.9 ARC-SECOND ANNULUS
VERSUS CUBE DIHEDRAL ANGLE - ON AXIS
(LAGEOS RETROREFLECTORS)
TOLERANCE STUDY
NOMINAL CUBE
ITEK INTERFEROGRAM
BENDIX MEASUREMENT
VERSUS ANGLES FROM
ITEK INTERFEROGRAMS
LAGEOS TEST
CUBE #
(RETROREFLECTOR)
3
6
1
4
2
5
1.0
1.5
2.0
2.5
DIHEDRAL ANGLE (ARC-SEC)
0
5
10
15
20
25
PERCENT ENERGY

FIGURE 5-1

FIGURE 5-2

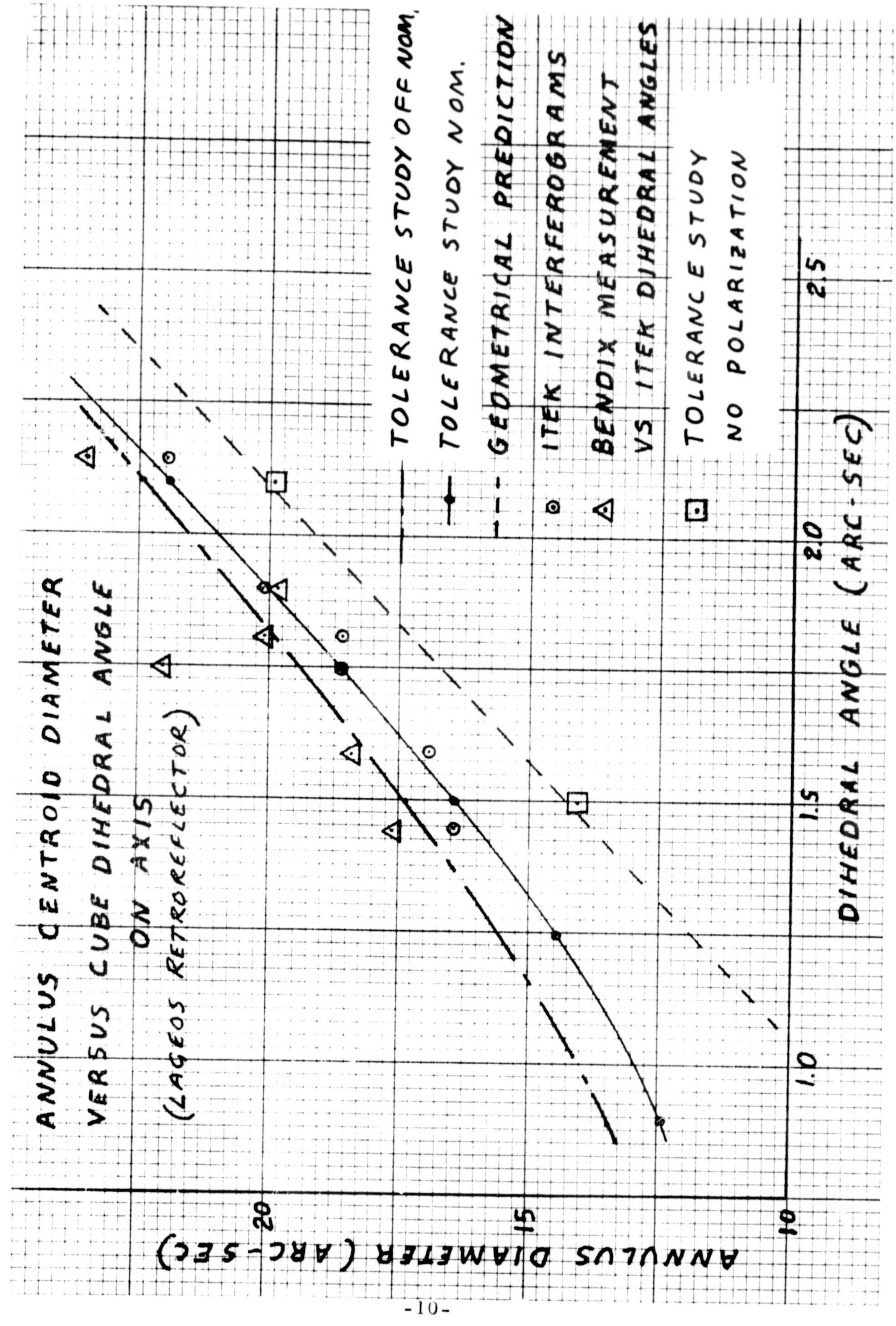
ANNULUS CENTROID DIAMETER
VERSUS CUBE DIHEDRAL ANGLE
ON AXIS
(LAGEOS RETROREFLECTOR)
TOLERANCE STUDY OFF NOM.
TOLERANCE STUDY NOM.
GEOMETRICAL PREDICTION
ITEK INTERFEROGRAMS
BENDIX MEASUREMENT
VS ITEK DIHEDRAL ANGLES
TOLERANCE STUDY
NO POLARIZATION
1.0
1.5
2.0
2.5
DIHEDRAL ANGLE (ARC-SEC)
10
15
20
ANNULUS DIAMETER (ARC-SEC)

Table 5-3

DIHEDRAL ANGLE MEASUREMENTS

REWORKED RETROREFLECTORS

RETROREFLECTOR S/N		DIHEDRAL ANGLES* (ARC SEC)	AVG. DIHEDRAL ANGLE (ARC SEC)
1 RW	1-2	0.97	0.98 AVG.
	2-3	1.10	
	3-1	0.86	
2 RW	1-2	1.37	1.29 AVG.
	2-3	1.26	
	3-1	1.24	
3 RW	1-2	0.72	0.79 AVG.
	2-3	0.84	
	3-1	0.82	

*BASED ON AVERAGE OF FIVE MECHANICAL MEASUREMENTS, MADE BY ZYGO CORPORATION.

TABLE 5-4

INTERFEROMETRIC MEASUREMENT OF DIHEDRAL ANGLES

ON REWORKED RETROREFLECTORS (ARC-SEC)

Reworked Retroreflector S/N	INTERFEROGRAMS * 1	INTERFEROGRAMS * 2	INTERFEROGRAMS * 3	Average	Avg.
1 RW	0.73 0.30 0.45	0.79 0.38 0.33	0.83 0.28 0.30	0.78 0.32 0.36	0.49
2 RW	0.67 0.89 0.77	0.58 0.91 0.73	0.91 0.79 0.59	0.72 0.86 0.70	0.76
3 RW	0.28 0.17 0.40	0.24 0.30 0.16	0.25 0.26 0.30	0.26 0.24 0.29	0.26

*Based on Interferograms Produced by Zygo Corp. and Analyzed by Itek Corp., Optical Systems Division

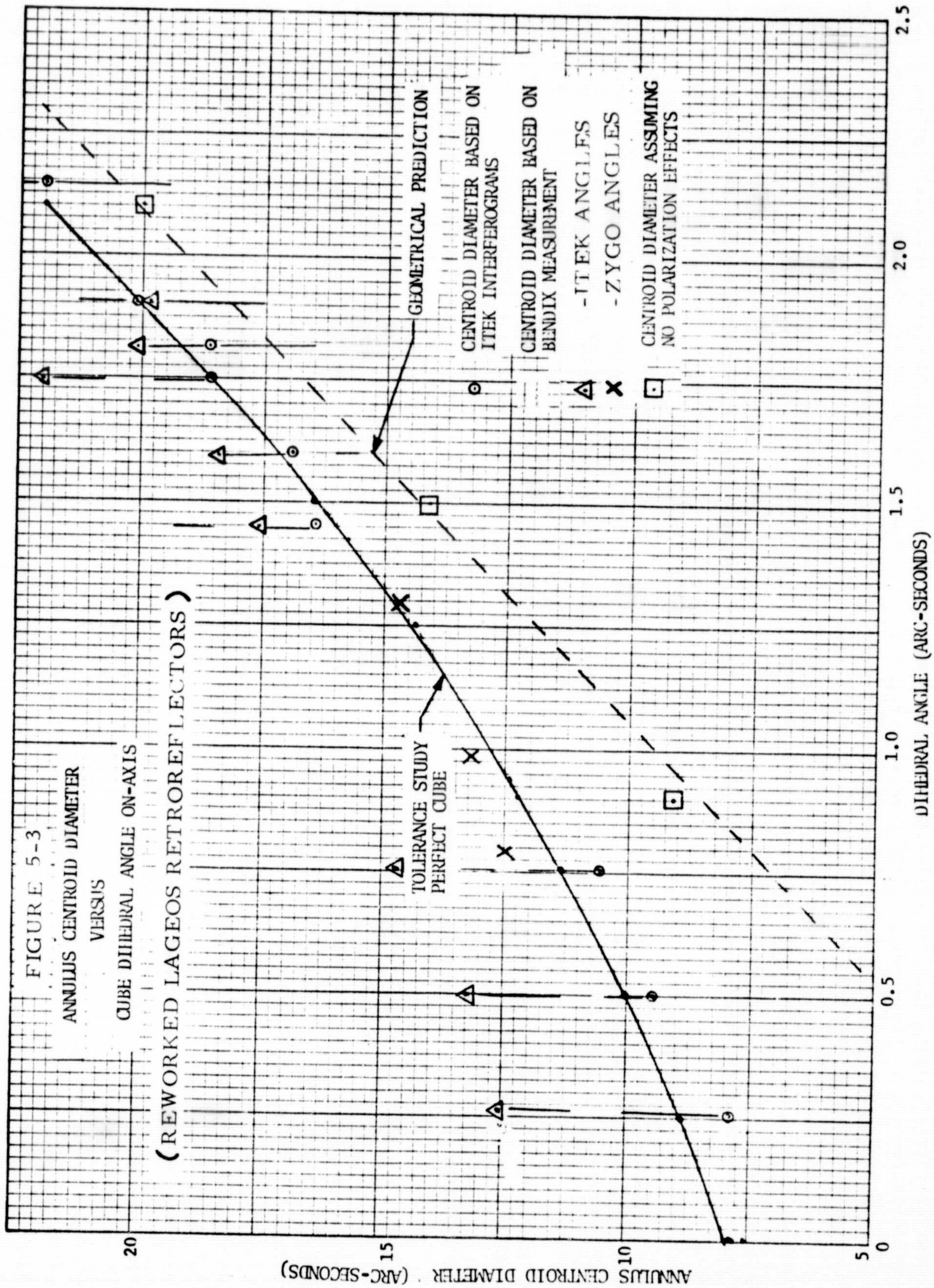
FIGURE 5-3
ANNULUS CENTROID DIAMETER
VERSUS
CUBE DIHEDRAL ANGLE ON-AXIS
(REWORKED LAGEOS RETROREFLECTORS)
GEOMETRICAL PREDICTION
TOLERANCE STUDY
PERFECT CUBE
CENTROID DIAMETER BASED ON
ITEK INTERFEROGRAMS
CENTROID DIAMETER BASED ON
BENDIX MEASUREMENT
-ITEK ANGLES
-ZYGO ANGLES
CENTROID DIAMETER ASSUMING
NO POLARIZATION EFFECTS
DIHEDRAL ANGLE (ARC-SECONDS)
ANNULUS CENTROID DIAMETER (ARC-SECONDS)
0
0.5
1.0
1.5
2.0
2.5
5
10
15
20

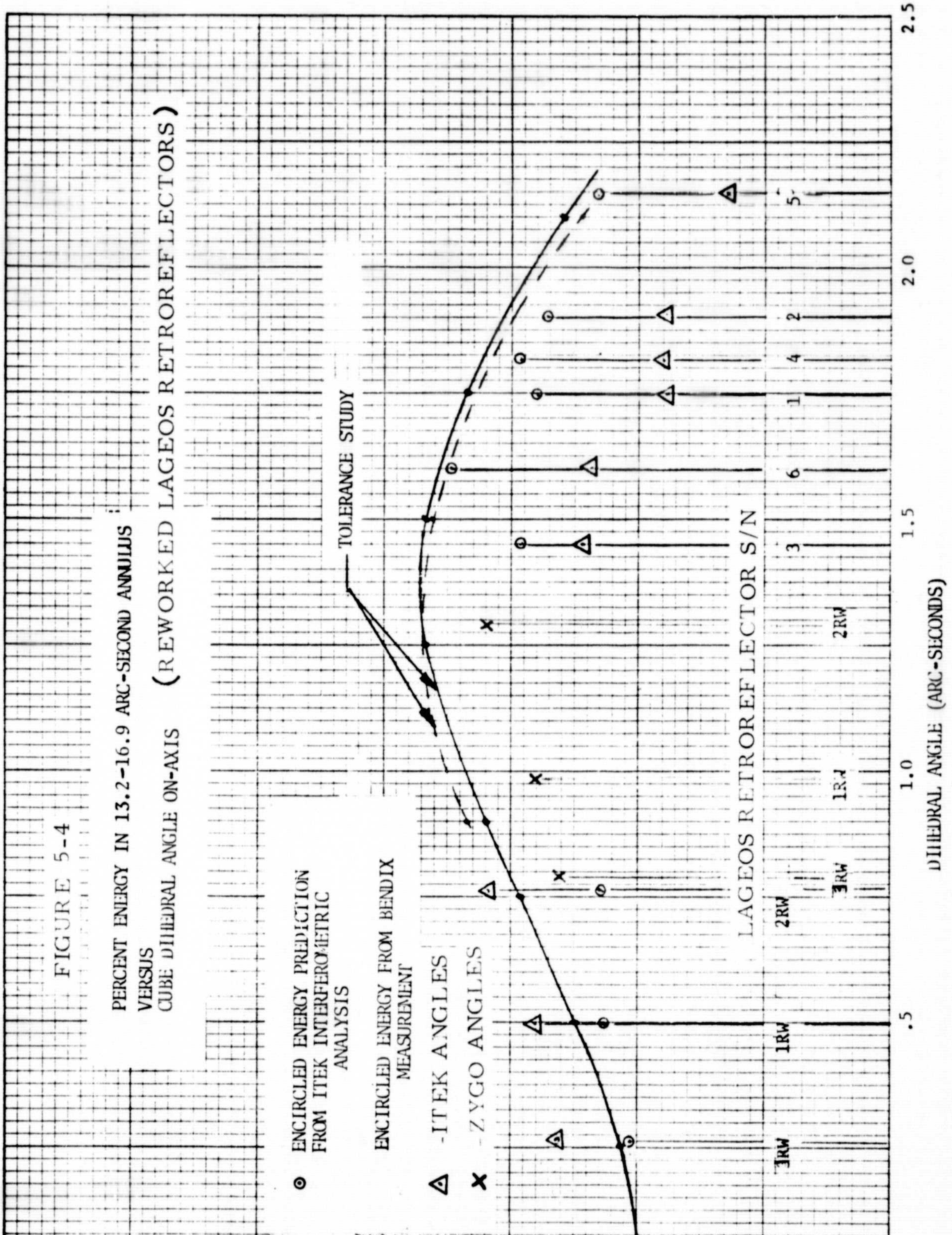

FIGURE 5-4

PERCENT ENERGY IN 13.2-16.9 ARC-SECOND ANNULUS
VERSUS
CUBE DIHEDRAL ANGLE ON-AXIS

(REWORKED LAGEOS RETROREFLECTORS)

determined and the mechanically determined dihedral angles. The optical test results for the reworked retroreflectors are also included in Figures 5-3 and 5-4. A detailed description of the optical tests is given in Section 7 of Volume II.

A test was conducted in the early phase of this study to experimentally confirm that the retainer ring of the retroreflector mount hardware has no effect on the optical test measurements. The test article, test instrumentation, and test results are summarized in Table 5-5.

Although not directly a part of this study, results of an analysis performed in the NASA/MSFC Optics Group are included as these results supported the selection of the LAGEOS dihedral angle specification. The MSFC study analyzed the structure of the far-field diffraction pattern as a function of laser wavelength and the proposed dihedral angles. The theoretical far-field diffraction pattern was predicted for average dihedral angles of 90° + 1.5 arc-sec and 90° + 1.25 arc-sec at wavelengths of 6,943 Å, 5,320 Å, and 3,500 Å. The results for a wavelength of 3,500 Å and a dihedral angle of 90° + 1.25 arc-sec are shown in Figure 5-5; data for other wavelengths and dihedral angles are given in Section 9 of Volume II.

5.2 Significant Results

The conclusions resulting from the data generated in this study are summarized as follows:

- Based on wide variations in the mechanical measurements data, it was concluded that mechanical measurements of dihedral angles in the LAGEOS range (90° + 0.5 to 2.5 arc-sec) are unreliable and not repeatable. The use of interferograms is recommended as a primary method of determining the dihedral angles of a retroreflector, as interferograms provide a direct measurement of the effect of dihedral angle on the wavefront of the emerging return beam.

- The dihedral angles of the original LAGEOS test retroreflectors were determined to be on the high side of the nominal dihedral angle (90° + 1.5 arc-sec), and the average dihedral angle of the six LAGEOS test retroreflectors was 90° + 1.8 arc-sec.

- Based on far-field intensity distribution predictions, which include polarization and diffraction effects and the effects of unequal dihedral angles, the optimum nominal dihedral angle for the LAGEOS application was found to be 90° + 1.25 arc-sec. The original LAGEOS nominal dihedral angle specification was 90° + 1.5 arc-sec on the basis of geometric considerations.

TABLE 5-5

EFFECT OF RETAINER RING ON OPTICAL PERFORMANCE

. TEST ARTICLE:
- ALSEP FLIGHT RETROREFLECTOR (S/N 415-A)
- INSTALLED IN CAVITY "B" OF LAGEOS TEST ARTICLE PANEL
- REMOVABLE MASK TO EXPOSE ONLY THE RETROREFLECTOR FACE (FLAT BLACK SURFACE)

. TEST INSTRUMENTATION: - FAR-FIELD DIFFRACTION INSTRUMENT

LASER POLARIZATION: LINEAR @ 0^{o}

. RESULTS:

RETRO TYPE	CALIB.	ALSEP	ALSEP	ALSEP
MASK	NO.	NO	YES	NO
PHOTO NO.	1	2	3	4
LASER	0.83	0.83	0.83	0.83
FFDP-ANNULAR	0.14	0.14	0.15	0.15
RATIO-ANNULAR	0.17	0.18	0.18	0.18
RATIO-FULL FIELD	1.13	1.20	1.22	1.22
ANNULAR/FULL FIELD	0.14	0.15	0.14	0.14
BIAS	—	0.007	—	-0.007

. CONCLUSIONS:

NO MEASURABLE LASER RETURN FROM RETAINER RING

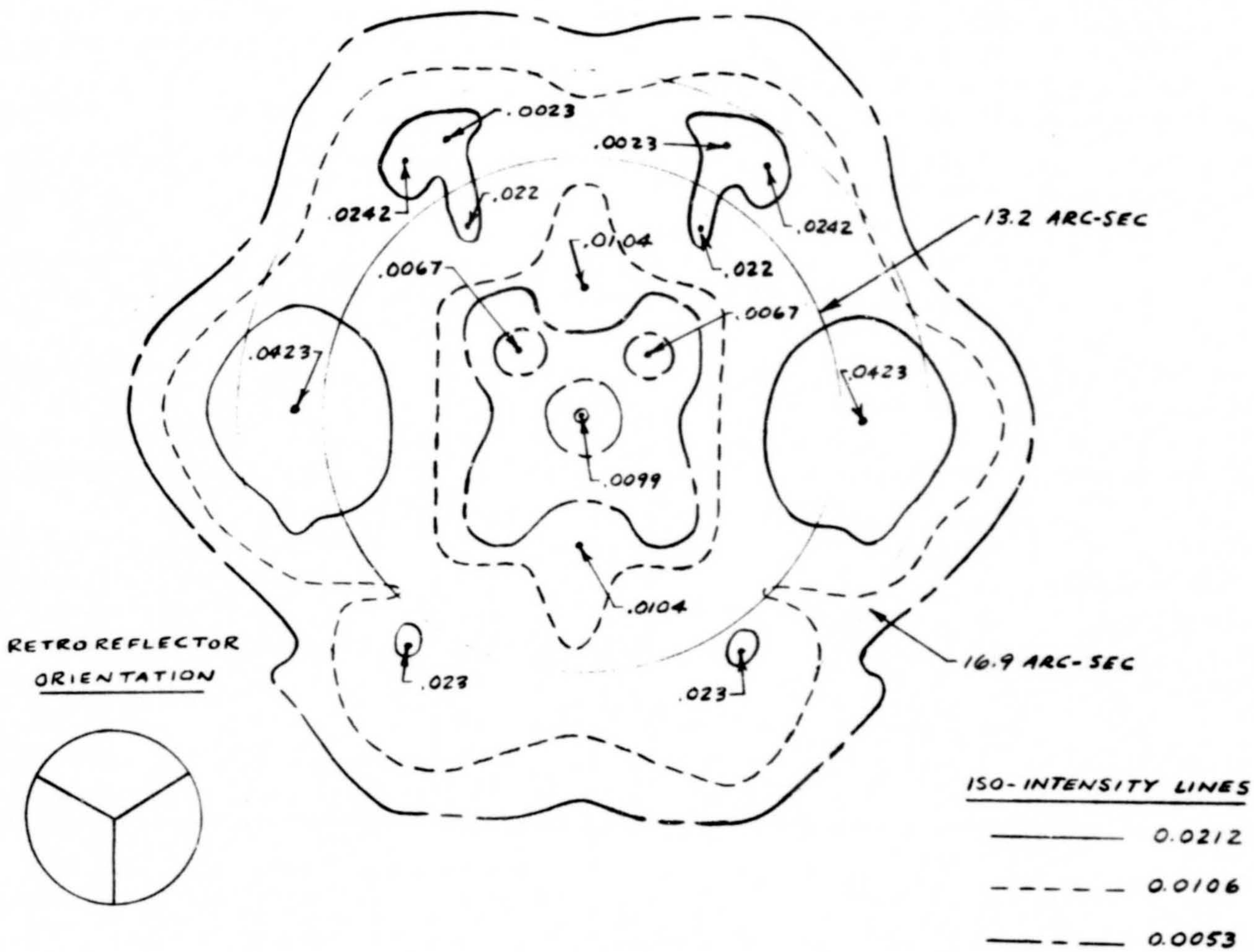

Figure 5-5 PREDICTED RELATIVE INTENSITY DISTRIBUTION IN FFDP
(λ = 3500 Å AND α = 90° + 1.25 ARC SEC)

- Comparison of test and analytical performance for the original LAGEOS test retroreflectors, with the predicted far-field intensity distribution as a function of dihedral angle, illustrates that the differences between the analytical predictions and test results in the original study effort (Ref. A) were due, in part, to the higher-than-nominal dihedral angles of the LAGEOS test retroreflectors.

- Both the test results and analytical predictions for the LAGEOS test retroreflectors reworked to a set of lower dihedral angles confirmed the earlier predictions of a performance optimum at 90° + 1.25 arc-sec and a decrease in performance for lower dihedral angles.

- An unexplained uniform discrepancy resulted between the mechanically determined dihedral angles and the interferometrically determined dihedral angles of the reworked retroreflectors.

- Differences between test measurements and anlytical predictions of optical performance for the LAGEOS test retroreflectors, both original and reworked, remain unexplained. There is relatively good agreement between test and analytical results for the centroid of the relative intensity in the far-field. However, measured relative intensity is less than predicted for the LAGEOS test retroreflectors at dihedral angles above the optimum and, higher than predicted at the lower dihedral angles.

- Based on the results of the retainer ring optical tests, it was concluded that no measurable laser return is reflected from the retainer ring and, therefore, the retainer ring has no effect on optical test results.

- In the wavelength effects evaluation, each wavelength produced similar types of structural changes in the far-field pattern with decreasing dihedral angle. These changes were a reduction of overall pattern size, an increase in the intensity of the maximum points, and an increase in the intensity near the axis. Because the tests and analyses verified that an improvement in performance was obtained by reducing the dihedral angle for a wavelength of 6,328 Å, it was concluded that the LAGEOS return signal strength would be stronger at all wavelengths if the dihedral angle was changed from 90° + 1.5 arc-sec to 90° +1.25 arc-sec.

6.0 STUDY LIMITATIONS

The study was limited to the accomplishment of the tasks identified in the Study Plan (Ref. B) and outlined in Section 4. Based on the results of the study, these tasks were found adequate to accomplish the overall objectives set forth at the start of the study, as described in Section 2 and defined in the Study Plan.

The results of these test and analytic efforts did identify some as yet unanswered questions which did not, however, prohibit the accomplishment of the study objectives. Rather, these questions reflect the very limited amount of investigation and research performed to date on the uncoated solid fused-silica retroreflector. This study effort and the previous basic study (Ref. A) have provided a significant increase in the understanding of retroreflector phenomena. The LAGEOS application, the Apollo LRRR applications, and the planned future space applications of retroreflector technology warrant the pursuit of additional investigations to increase our understanding of the optical performance of retroreflectors.

7.0 IMPLICATIONS FOR RESEARCH

As noted in the previous final report (Ref. A), the availability of LAGEOS test retroreflectors and mounting hardware, Bendix test facilities and equipment, and in particular, the Far-Field Diffraction Instrument, permit additional testing of these retroreflectors for the purpose of developing a better understanding of the effects of various parameters on optical performance. Additional testing and analysis may also provide the basis for answering the remaining questions on differences noted between test and analytical results. The test and analytical capabilities developed by the Bendix-Itek-Zygo team, which were utilized in this study, can also be adapted to the feasibility study and preliminary design of other laser-retroreflector space applications.

8.0 SUGGESTED ADDITIONAL EFFORT

The following summarizes the recommendations for additional effort, as identified in the evaluation of these study results:

- Perform additional thermal/optical analysis and test effort on the LAGEOS test retroreflectors to more fully explore the effects of various retroreflector and laser design parameters.

- Investigate the differences between the optical test results and analytical predictions by performing additional tests and analyses to identify, in greater detail, the energy distribution in the far-field

pattern. This task would include a reverification of the test and analytical methods.

- Extend, in a program of analyses and tests, the present understanding of optical performance to other sizes and types of retroreflectors, to coated retroreflectors, and to open-corner retroreflectors.

9.0 REFERENCES

The following documents are referenced in this report:

A. Final Report - Laser Geodynamic Satellite Thermal/Optical/Vibrational Analyses and Testing, Bendix Document BSR 4159, dated October 1974.

B. Study Plan - Laser Geodynamic Satellite (LAGEOS) Thermal/Optical/Vibrational Analyses and Test Program, Bendix Document LAGEOS-8, Revision C, dated 8 November 1974.